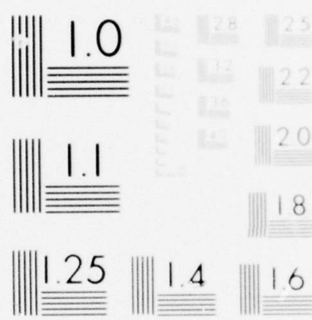
AD-A044 715 BATTELLE COLUMBUS LABS OHIO F/G 13/8
HYDROGEN IN HY-130 WELD METAL.(U)
JUL 77 D G HOWDEN, R M EVANS N00014-74-C-0407
UNCLASSIFIED NL

| OF |
AD
A044715

END
DATE
FILMED
10-77
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

(12)

OFFICE OF NAVAL RESEARCH
CONTRACT NO. N00014-74-C-0407 (NR 031-770)

ANNUAL REPORT ON

HYDROGEN IN HY-130 WELD METAL

July 31, 1977

by

D. G. Howden and R. M. Evans

Battelle
COLUMBUS LABORATORIES
505 King Avenue
Columbus, Ohio 43201

(15) OFFICE OF NAVAL RESEARCH
~~CONTRACT NO.~~ N00014-74-C-0407 (NR 031-770)

(9) ANNUAL REPORT, ON
no. 3, Jul 76 - Jul 77,

(6) HYDROGEN IN HY-130 WELD METAL.

(11) 31 July 31, 1977

(12) 28p.

by

(10) D. G. Howden and R. M. Evans

Battelle
COLUMBUS LABORATORIES
505 King Avenue
Columbus, Ohio 43201

1473

407 080

LB

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Annual Report No. 3	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) HYDROGEN IN HY-130 METAL		5. TYPE OF REPORT & PERIOD COVERED Annual July 1976-July 1977
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) D. G. Howden and R. M. Evans		8. CONTRACT OR GRANT NUMBER(s) N00014-74-C-0407
9. PERFORMING ORGANIZATION NAME AND ADDRESS Battelle Columbus Laboratories 505 King Avenue Columbus, Ohio 43201		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Procuring Contracting Officer Office of Naval Research Dept. of the Navy, Arlington, VA. 22217		12. REPORT DATE July 31, 1977
		13. NUMBER OF PAGES
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office) Chief, Defense Contract Administration Services Office, Columbus c/o Defense Construction Services Supply Ctr. Bldg 1 Sec 1, Columbus, Ohio 43215		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

REPRODUCTION OF THIS REPORT IN WHOLE OR IN PART IS PERMITTED FOR ANY PURPOSE OF THE UNITED STATES GOVERNMENT.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

WELDING
HY-130
HYDROGEN
EMBRITTLEMENT

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes progress in producing evaluating welding electrodes containing known amounts of rare earth metal for reducing hydrogen embrittlement in HY-130 steel welds. Prior work indicated rare earth silicides lowered the notch strength of welds. In this report studies directed toward the use of rare earth-nickel additions as a possible means of improving this property while retaining the desirable effects of the rare earths. Results to this time indicate notch strength lowering by the rare earth-nickel also.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Acknowledgements

The work performed under this contract was supported and monitored by the Office of Naval Research, Metallurgy Program directed by Mr. P. A. Clarkin. This support is appreciated together with that of Dr. Bruce A. MacDonald (ONR, Arlington) and Dr. George Sandoz (ONR, Chicago) both of whom provided a personal interest.

In addition, the assistance of Mr. A. Pollack, NSRDC, in providing HY-130 base plate and welding wire is greatly appreciated. The prompt delivery of special cored welding wires by Hobart Brothers Company aided greatly in the progress of the program.

INTRODUCTION

This is the third annual report on a study of "Hydrogen in HY-130 Weld Metal", Contract No. N00014-74-C-0407. The period covered is from July, 1976, to July, 1977.

Hydrogen can cause cracking in both the weld heat affected zone and weld metal of high yield strength steels such as HY-130. In these steels delayed cracking results from the presence of hydrogen in combination with a hard structure and residual stresses. Presently many precautions are utilized when gas metal-arc welding these steels in order to meet required mechnical properties in weldments. The present study has as its objective the elimination of hydrogen related problems in welds by using additives in the weld metal which will chemically combine with the hydrogen to render it innocuous.

During the initial years work on this program* it was shown that an addition of getter materials (misch metal) to HY-130 steel would tie up the diffusible hydrogen. Misch metal contents in the range 0.1 to 0.2 percent in experimental steels were capable of gettering hydrogen in steel in arc melting atmospheres of up to 5 percent hydrogen. Also, specially made short lengths of filler wires containing about 0.2 percent misch metal operated without significant effect on arc characteristics. Problems of considerable magnitude were shown to exist in the fabrication of welding wires in useful production lengths containing enough misch metal to overcome arc losses and give the desired weld metal composition. A 0.2 percent rare earth steel was fabricated into 1/16 inch (1.59 mm) wire only with difficulty. Steels with higher than 0.2 percent misch metal were too hot short to allow suitable wire fabrication.

Efforts during the second year of the program** took 2 directions: (1) toward perfecting a method of producing electrode wires containing a pure misch metal core, and (2) toward utilization of commercially fabricated experimental electrode wire having a rare earth silicide core.

---

* Annual Report, ONR Contract No. N00014-74-C-0407 (NR031-770), dated July 31, 1975.

** Annual Report, ONR Contract No. N00014-74-C-0407 (NR031-770), dated July 31, 1976.

The successful fabrication of misch metal-steel composite welding wire was not realized because of cracks that developed in the wire during the rolling and drawing operations. These cracks appeared to initiate from fins formed and rolled into the surface during the rolling operation. The cracks thus formed resulted in wire with continuous longitudinal splits. A second contributing factor was the low temperature used in the heat treat cycle, it was not high enough to remove prior cold work in the steel, thus making it more susceptible to crack propagation. Measures designed to overcome the difficulties encountered have been outlined but not pursued.

The specially made electrode wire having a rare earth silicide core rather than misch metal was evaluated by cold-wire addition to welds being made with Airco AX-140 electrode wire. Several problems were encountered. Both the silicon content of the wire and the method of addition seemed to be causes of these problems.

Hydrogen gettering tests showed that silicon did not reduce the potency of the rare earths present. But, adding it resulted in a weld metal containing over 0.50 percent silicon. These welds show significant reduction in notch toughness when compared to welds made without the additions. Therefore, work toward additions which do not adversely influence mechanical properties was indicated.

During the third year of the program which is the subject of this report the major effort has been aimed toward the development and use of cored electrode wires which do not contain silicon. To this end nickel-misch metal alloys have replaced misch metal silicide as the source of rare earths in the experimental electrode wires.

Considerable effort was also expended during this report period seeking a weld metal cracking test that could be used to economically evaluate the crack susceptibility of the experimental weld metals.

MATERIALS

Base Plate

The base metal being used for producing weldments is 1-inch-thick (25.4 mm) HY-140 grade steel plate having the following analysis.

Nickel	4.76 percent	Vanadium	0.08 percent
Manganese	0.84 percent	Copper	0.06 percent
Chromium	0.49 percent	Aluminum	0.03 percent
Molybdenum	0.36 percent	Carbon (total)	0.12 percent
Silicon	0.34 percent	Phosphorus	0.003 percent
Zirconium	0.11 percent	Sulfur	0.007 percent

Primary Steel Electrodes

Two primary electrode wires for welding were furnished by the Sponsor. One was an experimental wire known as AX-140 and is 1/16 inch (1.59 mm) in diameter, bare and bright. It was produced by Airco Welding Products and is recorded as Heat Number 51252 Lot LK4. The second was also an experimental wire designated as Linde 140S, 1/16 inch (1.59 mm) in diameter and came from Heat Number 151140.

The AX-140 wire was used in all early work during the period covered by this report. After receipt of the 140S wire it became the major wire used. The data cited identifies the wire in specific experimets.

Rare Earth-Nickel Cored Electrode Wire

As a method of producing a weld metal which should have better ductility than when misch metal silicide is added to getter hydrogen it was decided to use a rare earth-nickel powder alloy. This special alloy was produced by Novamet of Waldwick, N.J. Two lots of it were used during the present report period. Their composition is given in Table 1.

TABLE 1. COMPOSITION OF RARE EARTH-NICKEL ALLOY POWDER

	Weight Percent					
Heat Number	Ni	Rare Earth	Al	C	O	N
T-80086	68.1	32.0	0.14	0.004	0.010	0.0022
T-80837	68.3	32.0	--	0.005	0.030	0.0030

Hobart Brothers, Troy, Ohio, produced three lots of 0.045 inch (1.14 mm) diameter wire containing the rare earth-nickel powder for use during the report period covered.

Cored Electrode Wire Lot No. FF8-115-2

This wire was designed to contain 10 percent rare earth metal-nickel powder; the actual composition as produced was 10.1 per percent. The remainder of the wire was nominally 80 percent low carbon sheath and 10 percent iron powder. As received this wire was slightly oversize (0.045 in. 51.14 mm), was discolored (nearly black) and the seam in the sheath was slightly open. Fifty pounds of this lot of wire were received. The rare earth-nickel powder used was from Heat No. T80086.

Rare earths were placed in the weld metal by cold feeding the cored wire containing the additive into the forward edge of the molten-pool made by the gas metal arc weld. Bead-on-plate weld pads were made for analysis of the rare earth content using welding parameters found suitable earlier for making cold wire additions. The addition rate used was calculated to produce a weld metal containing approximately 0.12 percent rare earth based on past recovery experiences. Subsequent spectrographic analysis of the weld metal produced showed less than 0.004 percent rare earth when using either argon or argon plus 2 percent oxygen as the arc shielding gas.

Based on the physical condition of this lot of wire, and observation that the wire was losing core material as it was uncoiled during welding, plus the analysis of the weld metal led to a concern about its usefulness for the intended purpose. Consequently, hydrogen gettering tests (see annual report July 31, 1975, pp. 12) were undertaken to determine the hydrogen tie-up capabilities of this rare earth-nickel containing wire. The results indicated that the subject wire did not introduce sufficient rare earth elements to getter hydrogen.

As a consequence of the hydrogen gettering tests results it became desirable to determine whether the rare earth-nickel alloy would infact tie-up hydrogen in a weld metal. This was done by melting 10 g buttons of AX-140 filler metal wire under argon, drilling holes in them of varying volume, filling the holes with rare earth-nickel powder

and then performing the usual hydrogen gettering tests on these composite buttons. The results showed that the rare earth-nickel alloy would tie-up the hydrogen. They showed also that approximately 0.25 percent rare earth was needed to eliminate hydrogen evolution during the test. This was a good check on past work; a recovery efficiency of the order of 30 to 40 percent is valid for these experiments.

It was apparent after the two series of hydrogen gettering tests that the "gettering quality" of the subject wire had been affected by the fabrication procedure. Therefore the manufacturer was contacted and these factors important to the possible usefulness were learned.

(1) The dark color is ordinarily not harmful, it is a function of the strip making procedure and the wire lubricant used.

(2) Lubricant residue (carbon) has been found on finished wire.

(3) The wire is baked in air at temperatures up to 600 F (315 C) to deactivate or remove lubricant. Baking temperature depends on lubricant used.

(4) Oxidation of the core does occur and is quite variable depending on strip variations and die wear.

Thus, the possibility existed that the desirable properties of the rare earth-nickel core material was lost due to oxidation or other alterations most likely during the baking step of the wire making procedure.

To determine whether or not the core of the wire had been oxidized X-ray diffraction (XRD) analyses were made on the as-received rare earth-nickel alloy powder, on this same powder after heating for 3 hours in air at 625 F (330 C) and on very small samples of powder as recovered from the as-received cored wire. The compounds identified are shown in Table 2. The patterns were taken in a 57.3 mm Debye-Scherrer camera using CuKα X-radiation. Compound identification was obtained by matching the experimental patterns against standard patterns in the Powder Diffraction File (PDF) maintained by the Joint Committee on Powder Diffraction Standards. The compound ($RENi_5$) represents a rare earth-nickel alloy with a hexagonal cell. While this compound is not listed in the file there

are several analogous compounds given such as $CeNi_5$, $LaNi_5$, $PrNi_5$, $NdNi_5$, etc. The rare earth atoms appear to occupy sites in the lattice necessary to produce a pattern. The compound listed as Fe_3O_4 probably contains some Ni and rare earths, since agreement with the standard pattern is not good as normally observed. No patterns of rare earth metals were observed except the alloy.

TABLE 2. X-RAY DIFFRACTION OF WIRE CORE MATERIALS

Sample	Compound	PDF #	Pattern Strength[(a)]
Powder	$(RENi_5)^{(6)}$	--	Very strong
(as received)	Ni	4-850	Very strong
Powder after heating	$(RENi_5)$	--	Very strong
330° C-3hrs	Ni	4-850	Medium weak
(626 F)	CeO (Cerianite)	4-593	Weak
Wire, powder core	NiO (Bunsenite)	4-835	Strong
	(Fe)2B(Kamacite)	6-696	Medium
	Ni	4-850	Medium
	Fe_3O_4	19-629	Medium
	CeO	4-593	Medium weak

(a) Pattern strength is the intensity of the strongest line of a compound's pattern. It services as a rough quantitative estimate.

(b) This compound appears analogous to $(CeNi_5)$. The lattice parameters are a_o=4.907, c_o 4.009.

The XRD analysis shows that simple air oxidation of the rare earth-nickel alloy powder is not serious at 330 C (626 F). The picture is not as clear for the powder removed from the wire. However since extensive oxidation apparently took place at the same temperature, this may be related to the presence of lubricant and the iron powder in the wire core. Analytical results show that both the nickel and the iron appear to alter significantly while the presence of metallic rare earths seems lost.

No further welding work was undertaken with wire from Lot No. FF8-115-2 because of the evidence presented that this wire was not suited for tying up hydrogen in the weld metal, because of preoxidation (or nitrodation). Arrangements were made to produce cored wire containing rare earth-nickel powder which was not subjected to the lubricant bake-off step.

Cored Electrode Wire Lot No. FF8-115-3

This wire was prepared using the neat rare earth-nickel powder. The fill content, determined after fabricating to 0.045 inch (1.14 mm) diameter wire was 16.9 percent powder or 5.4 percent rare earths. The wire was not cleaned beyond the normal wiping after drawing and no baking was allowed. Three pounds of this lot were received, it consumed all of the rare earth-nickel alloy on hand (Heat No. T80086).

Hydrogen gettering tests using buttons made from AX-140 welding electrode wire and varying quantities of the new rare earth-nickel cored wire. The results indicated that the contained powder was capable of tying-up the diffusible hydrogen remaining in the button when it was melted under either argon +0.5 or +2.0 percent hydrogen.

On the basis of the tests described work proceeded on the production of welds containing rare earth-nickel additions to eliminate delayed cracking caused by hydrogen.

Cored Electrode Wire Lot No. FF8-115-4

The third lot of cored wire used during this report period was designed to contain 10 percent of the rare earth-nickel powder. It was not cleaned nor baked after drawing. Twelve pounds of 0.045 inch (1.14 mm) diameter containing rare earth-nickel powder from Heat No. T80837 were received.

Several hydrogen gettering tests on buttons were made from Linde 140S (Heat No. 151140) wire and the wire from Lot No. FF8-115-4. The calculated rare earth content of these buttons assuming a 35 percent recovery, ranged from 0.06 to 0.33 percent. The results showed that the diffusible hydrogen was tied-up in all buttons containing a calculated

0.13 percent or more rare earth. Thus the experimental wire from Lot No. FF8-115-4 was considered useful for producing test welds.

EXPERIMENTAL WELDING

Cracking Tests

Gapped Bead-on-Plate (GBOP) Tests

As indicated previously it was desirable in this research program to find an economic cracking test suitable for evaluating the effect of rare earth additions on HY-130 weld metals. Thus it was decided to examine the usefulness of the recently developed GBOP (gapped bead-on-plate) test* for this purpose. In comparison with other weld metal hydrogen cracking tests, this method is simple and inexpensive. Yet, it is used to quantitatively determine the effects of important welding variables on cracking susceptibility.

The basic test comprises two blocks clamped together with a gap formed by a groove machined in one of the blocks as shown in Figure 1. After depositing the weld bead as indicated in Figure 1, it is set aside for 12 to 72 hours to allow adequate time for delayed cracking. The test weld is examined by removing the clamp, heating the weld bead to a dull red with a torch to heat-tint any cracked surfaces, allowing the weld to cool, and fracturing the weld across the gap. Cracking appears as a blue thumbnail on the fractured weld metal surface. Other investigators have related the incidence of cracking in GBOP tests on shielded metal-arc welds to:

(1) the hydrogen content of the weld-metal deposit

(a) McParlan, M., and Graville, B. A., "Hydrogen Cracking Weld Metals", Weld. J. 55 (4) 95s-102x (1976).

(b) McParlan, M, and Graville, B. A., "Development of the GBOP Test for Weld Cracking", IIW-IX-922-75 (April, 1975).

(c) Graville, B. A., and McParlan, M., "Weld-Metal Cold Cracking", Metal Constr. and Brit. Weld, J., 6 (2) 62-3 (1974).

(2) the preheat temperature and cooling rate needed to prevent cracking

(3) the filler-metal composition and strength

(4) the welding process; shielded metal-arc, submerged arc, and flux-cored gas metal-arc welding

(5) the filler wires having the same nominal composition but purchased from different suppliers

(6) the level of restraint that was varied by modifying the test block geometry

(7) the test block composition.

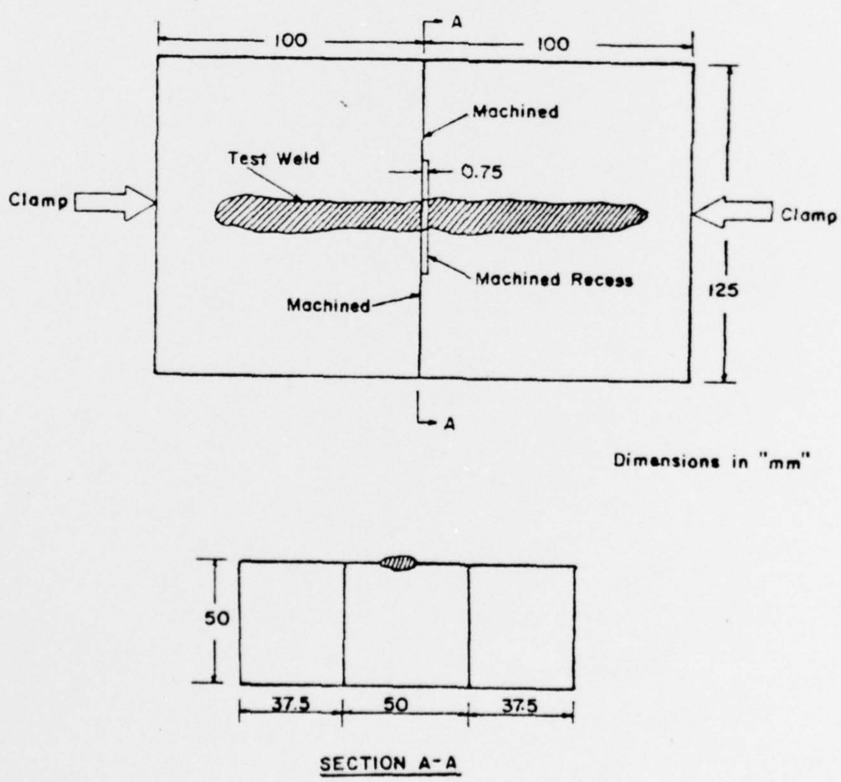


FIGURE 1. STANDARD GBOP (gapped bead-on-plate)[Ref. a]

In the present program the GBOP test was used essentially as outlined. The evaluation was made by making weld beads with the AX-140 standard electrode wire and argon shielding gas containing either 0.5 or 2.0 percent hydorgen. A total of 12 tests were made during which welding parameters were varied to obtain different heat imputs and weld penetration. The gap (notch sharpness) was also varied by making the weld across the butting part of the blocks away from the machined gap.

The results indicated that the test was not suitable for crack susceptibility testing in the current research program on gas metal-arc welding. No delayed cracks were found in any of the weld beads produced.

In connection with the work done with the GBOP tests one of its developers was contacted for comments. It was learned that others have had similar negative experience. The difficulties are attributed to differences in heat inputs, penetration and the chilling influence of the specimen. The test developer uses lower heat inputs and a thicker (greater heat sink) test block. The discussion indicated that significant test development work would be required to validate the GBOP test for our program. This was considered outside the objective of the program and work on the GBOP test was dropped.

Other Cracking Tests

Because the need for a simple test to evaluate the effect of rare earth additions on the HY-130 weld metal remained, three other techniques were examined:

(1) A spot fusion test made with a tungsten inert gas welding arc by melting a pool in the surface of a massive block of base metal. Filler metal and/or rare earth bearing wire could be added to the molten metal pool.

(2) Restrained V-groove weld tests made in short scrap pieces of base metal. Rare earth containing wire and hydrogen containing shielding gases could be used as desired for the particular test.

(3) Bead-on-plate tests in which rare earth additions and shielding gas could be varied to learn their influence on general cracking.

Spot Fusion Test. These tests were made by melting a spot in the center of the surface of a 3-inch square 1-inch-thick block of HY-140 steel. The spot was melted with a tungsten inert-gas torch at 380 amps and 18 volts. After the spot froze it was dye-penetrant checked for cracks after 1 hour and after 24 hours.

Spots were made under argon, argon plus 2 percent hydrogen and argon plus 5 percent hydrogen. AX-140 filler was added to one spot and a spot without filler metal was made under each gas. All but one test was made with the block at room temperature. The extra block was chilled in dry ice before the spot was melted and quenched immediately after welding.

None of the spots showed evidence of either hot or delayed cracking either before or after the bead was ground flush. This test was therefore abandoned.

Restrained V-Groove Test. The test specimen for this work was a short version (8 inches; 203 mm long) of the standard specimen given in MI-30-BE/1, "Procurement Specification Electrodes, Welding, Base, Solid . . . for Producing HY-130 Weldments for As-Welded Applications".

Radiographic results on 4 weld passes made in this specimen showed transverse delayed cracks when welded using argon plus 2 percent hydrogen shielding gas. No cracks were found in welds made with argon plus 2 percent oxygen gas. Thus a relatively inexpensive V-groove specimen can be used to show the influence of rare earth additions. Additional work with this specimen is reported later in this report.

Bead-on-Plate Tests. During this program bead-on-plate tests are made to establish the welding parameters for control of heat input, bead shape, arc stability, etc. This same test can be used to indicate when rare earth containing additions are excessive thus leading to the possibility of both hot and delayed cracking. In Table 3 the data for tests made to show the effect of rare earth wire additions and different shielding gases are given. The appearance of these beads-on-plate as dye-penetrant tested is shown in Figure 2.

The bead-on-plate data show that hot cracking can be expected if the calculated rare earth content is over 0.10 percent. Also it appears that the use of argon-oxygen shielding gas will permit higher rare earth additions. This is probably because the rare earths are

TABLE 3. INFLUENCE OF WELDING PARAMETERS ON CRACKING OF BEADS-ON-PLATE

Bead Identity	Welding Current, amp	Welding Voltage, V	AX-140 Wire Feed, ipm (m/min)	Rare Earth Wire Feed*, ipm (m/min)	Shielding Gas	Heat Input, kJ/in. (kJ/mm)	Calculated Rare Earth Addition** percent	Preheat, ° F (° C)	Comments
A	360	25	186(4.72)	65(1.65)	Ar	49.(1.93)	0.28	None	Cracked
B	336	25	176(4.47)	23(0.58)	Ar	46.(1.81)	0.10	None	Plate warm, no cracks
C	336	25	176(4.47)	42(1.06)	Ar	46.(1.81)	0.18	None	Cracked
D	352	24.5	176(4.47)	65(1.65)	Ar	47.(1.85)	0.28	250(121)	Cracked
E	336	25	176(4.47)	23(0.58)	Ar	46.(1.81)	0.10	250(121)	No cracks
F	336	25	176(4.47)	42(1.06)	Ar	46.(1.81)	0.18	250(121)	Cracked
G	304	25	176(4.47)	65(1.65)	Ar+2 O_2	41.(1.61)	0.28	None	Cracked
H	304	24	176(4.47)	23(0.58)	Ar+2 O_2	40.(1.57)	0.10	None	No cracks
I	304	24	176(4.47)	42(1.06)	Ar+2 O_2	40.(1.57)	0.18	None	Cracked

Note: Travel speed 11 ipm(0.28m/min); Shielding gas flow 40 cfh(1.13m^3/h).

* Lot No. FF8-115-3.

** Assumes 30 percent recovery.

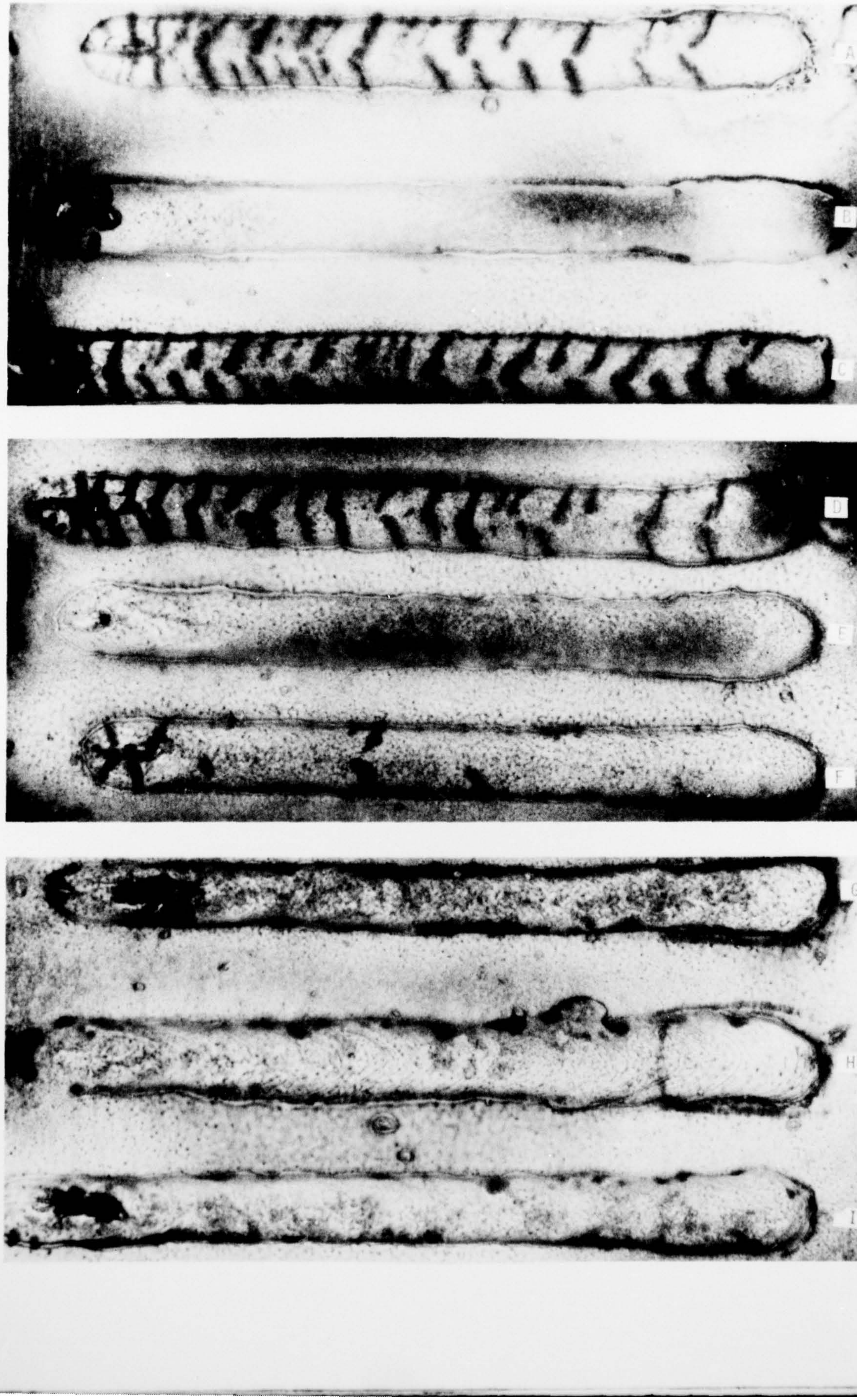


FIGURE 2. HOT CRACKING IN BEADS-ON-PLATE WELDS CONTAINING RARE EARTH ADDITIONS

oxidized and thus are not entering the weld metal. It is believed that the oxidizing effect is more important with respect to the cracking in this test than when lower heat inputs are recorded.

Tungsten-Arc Welding

During cracking test development work on the V-groove specimen difficulties were encountered when using the experimental wire from Lot No. FF8-115-3. This wire contained 5.4 percent rare earths and thus required careful control for the feed rates. At the acceptible gas metal-arc welding feed rates for the main electrode the feed rates of the rare earth bearing wire were quite low for accurate control in the available equipment. Nonuniform, premature melting of the cold wire by the arc was especially difficult to overcome at the slower feed rates.* Therefore tungsten arc welding using two cold wire feeds was examined as a method for making experimental V-groove welds. The advantage for tungsten arc welding for experimental purposes lay in the ability to vary both wire feed rates over a wide range. Thus any level of rare earth addition could be obtained with constant heat input.

After a preliminary series of bead-on-plate tests, tungsten arc welds using two cold wires were attempted in short V-groove specimens. No real improvement in results were found over those obtained when gas metal-arc welding and work with V-groove welds was stopped.

To determine whether or not an improvement in rare earth recovery efficiency was possible when tungsten-arc welding three spectrographic analyses were made on specimens made for this purpose. The additions made were of the same order of magnitude as those for gas metal-arc welding so that the data would be comparable. Table 4 shows the results. The data show that the use of a tungsten arc and two cold wires for producing welds containing rare earths is a much less efficient method of accomplishing the rare earth additions than the gas metal-arc process with either argon

---

* The same problems were the reason for the production of Lot No. FF8-115-4 to contain only 3.2 percent rare earths. This permits higher wire feed rates for equivalent additions.

TABLE 4. EFFICIENCY OF RARE EARTH TRANSFER IN A TUNGSTEN ARC[a]

Weld Identity	Welding Current, amps	Welding Voltage, V	Steel Wire Feed Rate, ipm (m/min)	Rare Earth Wire Feed Rate, ipm (m/min)	Travel Speed, ipm (m/min)	Heat Input, kJ/in. (kJ/min)	Rare Earths Added, percent	Actual Rare Earth Content, percent	Recovery Efficiency, percent
A	500	26.0	312(7.9)	25(0.64)	13.5(0.34)	57.8(2.3)	0.26	0.024	9.2
B	500	26.5	312(7.9)	20(0.51)	18.5(0.47)	43.0(1.7)	0.21	0.010	4.8
C	500	26.5	312(7.9)	30(0.76)	18.5(0.47)	43.0(1.7)	0.31	0.010	3.2

Note: Shielding gas flow rate 40 cfh($1.13 m^3/h$).

(a) Linde 140S steel wire - Lot No. FF8-115-3 rare earth wire; Argon shielding gas.

or argon-2 percent O_2 gas shielding. No effort was made to find the cause of the anomalous data for weld "A". It was expected that at the high heat input recovery of rare earths would be poorer rather than better than for the other tests.

Because no advantage in welding technique over gas metal-arc welding was found for tungsten arc welding and the rare earth recovery efficiency was low no further effort was expended on this process.

Residual Rare Earth Metal in Welds

It was desirable to learn whether or not any rare earth metal available for subsequent reactions remained in the completed weld. Residual rare earth metal might have one of several effects, among them:

(1) alter the weld metal mechanical properties,

(2) alter the corrosion properties of the weld metal,

(3) influence the results of repair welding operations.

A knowledge of the presence of the residual rare earth metals reactivity was gained by making hydrogen gettering tests on specimens of weld metal. These tests were made in the same manner previously reported. The data collected are summarized in Table 6.

It is evident from the data in Table 6 that little, if any, rare earth metal in the form needed to tie-up the diffusible hydrogen is present in any of the weld metals tested. In the case of welds made with pure argon shielding gas the data indicates that an addition of the order of one percent may result in the retention of active rare earth in the finished weld. Data on weld metals made under argon plus 2 percent O_2 do not show this indication.

The results of these experiments show that the rare earth-nickel alloy is most likely consumed by oxidation. Rare earth oxides included in the weld would be expected to slag off when the weld metal was remelted. The appearance of the test buttons did not indicate a slag coating.

TABLE 6. HYDROGEN GETTERING TESTS ON SELECTED WELD METALS

Weld Identification	Calculated Rare Earth Addition, percent	Actual Weld Rare Earth Content, percent	Weld Shielding Gas	Weight of Specimen G	Test Shielding Gas Hydrogen Content, percent	Length of Evolved Gas Column, in. (mm)	Length of Gas Column per unit Weight, in./g(mm/g)
3	0.80	--	Ar+2%O_2	9.75	2.0	1.03(26.1)	0.11(2.7)
4	0.52	--	Ar+2%O_2	9.66	2.0	0.75(19.0)	0.08(1.97)
V-8	0.40	0.054	Ar+2%O_2	9.64	2.0	1.25(31.8)	0.13(3.3)
1	0.77	--	Argon	9.90	2.0	0.56(14.3)	0.06(1.5)
G	0.40	0.220	Argon	10.75	2.0	1.40(35.6)	0.13(3.3)
2	0.28	--	Argon	9.92	2.0	1.06(26.8)	0.11(2.7)

Mechanical Test Specimen Production and Testing

Based on experience gained with the several welding procedural experiments, it was decided to make V-groove specimens for mechanical testing. Because of a shortage of base plate materials these specimens were designed to furnish mainly impact test pieces because in previous work the greatest effect of rare earth additions was noted in the notch toughness results.

The prior experience gained was also important because the equipment improvements made permitted satisfactory wire feeding uniformity. The shielding gas chosen for production of mechanical test specimens was argon + 2 percent oxygen. This was done because of the better weld bead quality obtained versus that produced when welding with pure argon but knowing the rare earth recovery was better when pure argon was used.

Pertinent welding and other information on the welds made for mechanical testing is given in Table 5. The specimens as-welded were either 8 or 18 inches (203. or 457. mm) long as indicated. In cross section they simulated, as nearly as available material would permit, the Specification MI-30-BE/1 for the procurement of HY-130 steel weldments. The finished weldment V-9 is shown in Figure 3.

The method used to place rare earths in the weld was to cold feed the wire containing the additive into the forward edge of the gas metal arc weld pool. The welding parameters were set suitable for normal operation using 1/16-inch (1.59 mm) diameter electrode wire. The 0.045 (1.14 mm) diameter cored wire was fed into the weld pool at a rate calculated to overcome arc losses and reach the desired rare earth concentration level. This rate was determined from available data and checked by the analysis of bead-on-plate welds when using cored wire of known rare earth metal content and a primary electrode feed rate of about 180 ipm (4.57 m/min). The results of these bead-on-plate analyses are included in Table 5. The data collected on the mechanical properties of welds made in the 1 inch (25.4 mm) thick HY-140 grade steel are given in Table 6. Also given in this table are the results obtained previously on welds made with rare earth silicide wire additions.

The data in Table 6 show that if the power input is in the order of 35. kJ/in. (1.14 kJ/mm) rare earth-nickel additions to the concentration

TABLE 5. WELDING, RARE EARTH ADDITIONS, AND INSPECTION DATA FOR WELDS TESTED MECHANICALLY

Weld No.	Specimen Length, in.(mm)	Current, amps	Voltage, V	Steel Wire Feed ipm (m/min)	Rare Earth Wire Feed, ipm (m/min)	Travel Speed ipm (m/min)	Calculated Rare Earth Additions, percent	Actual(5) Rare Earth Additions, percent	Heat Input kj/m (kj/mm)	Dye Penetrant Test After 24 hrs	Radiographic Results
V-5	8(203)	348	23.0	(1) 178(4.52)	(3) 22(0.56)	14(0.36)	0.31	0.112	34.3(1.4)	Clear	Good, minor lack of fusion at base
V-7	8(203)	356	22.5	(2) 178(4.52)	(3) 38(0.97)	11(0.28)	0.51	--	43.7(1.7)	Clear	Clear
V-8	8(203)	357	23.8	(2) 184(4.67)	(4) 56(1.42)	12(0.30)	0.40	0.054	42.4(1.7)	Clear	Minor lack of fusion at base
V-9	19(457)	356	23.7	(2) 180(4.57)	(4) 56(1.42)	12(0.30)	0.40	0.028	42.3(1.7)	Clear	Fair, minor porosity, may contain lack of fusion or poor bead wetting

NOTE: Shielding gas - Argon + 2 percent O_2 at 40 cfh (1.13 m^3/h) -- Contact tube to work distance 0.5 inch (12.7 mm).

(1) AX-140 welding wire Airco; 0.0625 inch (1.59 mm) diameter.

(2) 140 S welding wire Linde; 0.0625 inch (1.59 mm) diameter.

(3) Rare earth containing wire Lot Number FF8-115-3.

(4) Rare earth containing wire Lot Number FF8-115-4.

(5) Spectrographic analysis of pad made under identical welding parameters.

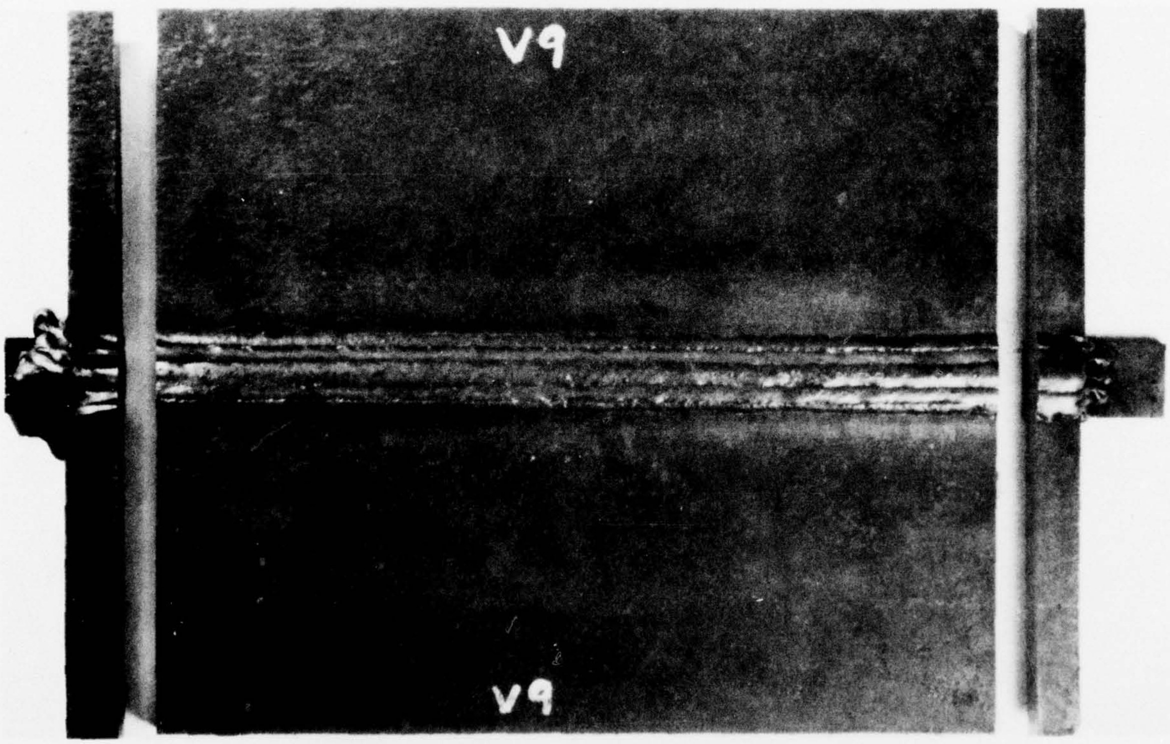


FIGURE 3. WELDMENT MECHANICAL PROPERTIES SPECIMEN V-9
AS WELDED AND WITH ENDS TRIMMED

TABLE 6. MECHANICAL PROPERTIES OF EXPERIMENTAL WELDS CONTAINING RARE EARTH-NICKEL ADDITION COMPARED TO PRIOR WORK WHEN RARE EARTH SILICIDE WAS ADDED TO THE WELD METAL

Weld Identification	Weld Metal	Shield Gas	Heat Input kJ/in.	Heat Input (kJ/mm)	Yield Strength* ksi	Yield Strength* MPa	Tensile Strength ksi	Tensile Strength MPa	Impact Strength CVN**, ft/lbs 30° F -1 C	Impact Strength CVN**, ft/lbs 77° F 25 C	Elongation percent, 1 inch
V-5	AX-140+RE/Ni	Ar+2% O_2	34.4	(1.4)	--	--	--	--	46	47	--
V-7	140S+RE/Ni	Ar+2% O_2	43.7	(1.7)	--	--	--	--	32	35	--
V-8	140S+RE/Ni	Ar+2% O_2	42.4	(1.7)	--	--	--	--	35	38	--
V-9	140S+RE/Ni	Ar+2% O_2	42.8	(1.7)	133.4	920.	150.8	1040.	22	27	21
5	AX-140+RES	Ar+2% O_2	46.	(1.8)	131.9	916.	155.9	1075.	42	53	23
6	AX-140	Ar+2% O_2	46.	(1.8)	130.7	900.	146.1	1009.	70	58	26
7	AX-140+RES	Argon	47.	(1.9)	138.7	956.	150.2	1035.	44	53	24
(a)	--	--	--	--	--	--	--	--	--	--	--
			45.0	(1.8)	145.0	1000.	--	--	50	50	14***

* Average of 2 specimens
** Average of 5 specimens each temperature
*** Elongation in 2 inches

(a) MI-30-BE/1 Requirements

level believed required can be made without some loss of toughness as compared to the specified property. When the heat input is around 42-43 kJ/in.(1.7 kJ/mm) there is a significant loss in toughness. This occurs even though the rare earth content of the weld metal is lower than desired.

The impact strength of the low heat input rare earth-nickel containing weld is lower at room temperature than obtained when rare earth-silicide additions were made. The rare earth-nickel weld metal may also have an influence on the transition temperature. In all cases the addition of rare earth metals reduces the notch strength of welds in HY-140 steel.

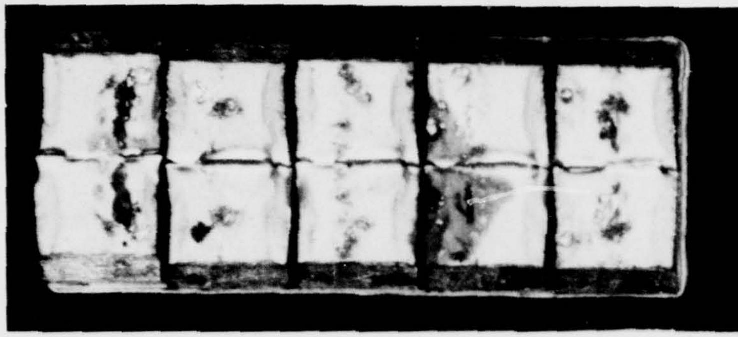
The very low impact properties of weld V-9 were evidenced by dark gray areas on the fracture surface as shown in Figure 4 which compares V-9 fractures with those for the best properties obtained. The possibility of this condition was anticipated from the weld radiograph. Macrographically these gray areas appear to indicate a lack of melting and mixing of the rare earth materials in the weld pool. No explanation was found for such an occurrence; one will be sought during projected metallographic and metallurgical work.

DISCUSSION

It is evident that the weld notch toughness is reduced when rare earth elements are added to the weld metal. The reduction appears greater when the rare earths were added as nickel compounds as opposed to silicon compounds. The reason for this is not obvious since additional nickel would be expected to improve toughness and silicon to reduce it. The answer may lie in the fact that silicon may offer more protection to the rare earth elements against oxidation, and that the rare earth oxide inclusions affect the toughness. Evidence that the rare earth elements were in fact, in nonmetallic compound form in the weld metal is twofold.

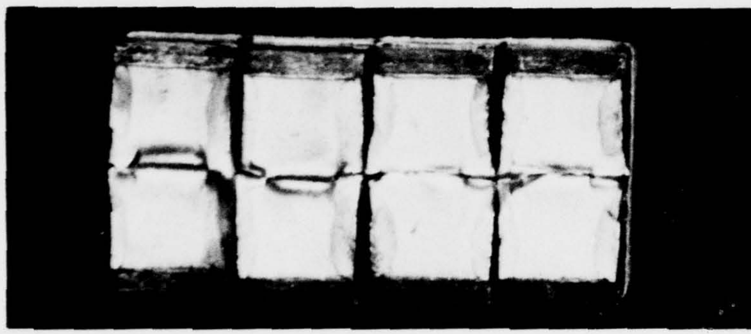
(a) Metallographic analysis of weld metal indicates that numerous spheroidal compounds were present within the grains. (Rare earths in metallic form are generally found as intergranular phases.)

(b) After welding, specimens taken from the weld metal lost their ability to getter hydrogen in a button

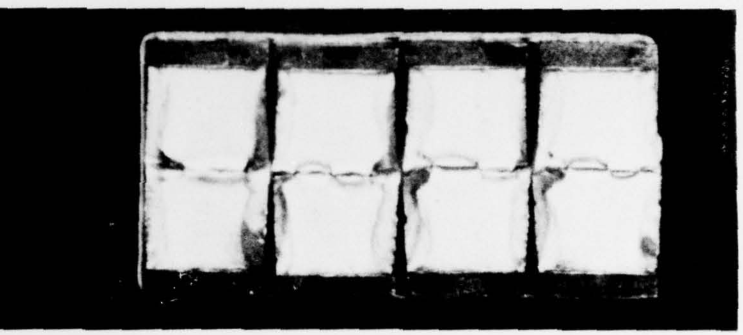


Weld V-9 Tested at Room Temperature

Weld V-9 Tested at +30 F (1.1C)



Weld V-5 Tested at Room Temperature



Weld V-5 Tested at +30 F (1.1C)

FIGURE 4. FRACTURE SURFACES OF GOOD (V-5) and BAD (V-9) WELDS

test indicating that the rare earths were in a more stable chemical form than is the hydride.

To estimate if oxygen from the arc atmosphere (Ar+2% O_2) could enter the weldmetal in sufficient quantities to combine with all the rare earth elements added a calculation of oxygen entry rate was made using same assumptions.

Howden and Milner* found that in the oxygen-titanium system oxygen was absorbed at a rate of 1.5×10^{-3} g sec^{-1}. Assuming that iron is capable of absorbing oxygen at the same rate (at least for dilute solutions of oxygen in iron), about 0.1 g min^{-1} was being absorbed by the steel. Rare earth was being added at a rate of approximately 0.3 g min^{-1} via the cored electrode. Assuming the trivalent form of the rare earth metals exists, 0.1 g of oxygen combines with approximately 0.6 g of rare earth metal. It is probable therefore that the rare earths introduced into the weld metal are fully oxidized during welding.

Welding in the future then must be carried out using a shielding gas of argon. When this has been tried in the past both hot cracking and a poor bead shape were encountered. The hot cracking was related to high recovery rates of rare earth elements and the poor bead shape to the absence of the wetting effect of oxygen on molten steel. These two items will receive primary attention by optimizing rare earth levels and arc variables. Welds in HY-130 steel will then be made to allow evaluation of mechanical properties and structure both with and without hydrogen contamination of the arc shielding gas.

---

* "Gas Absorption in Consumable Electrode Welding", D. G. Howden and D. R. Milner, Brit. Welding Journal 10, 395 (1963).